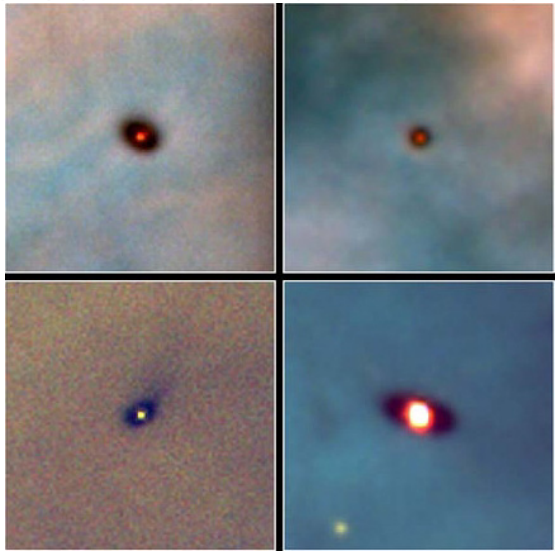
Evolution of Circumstellar Disks

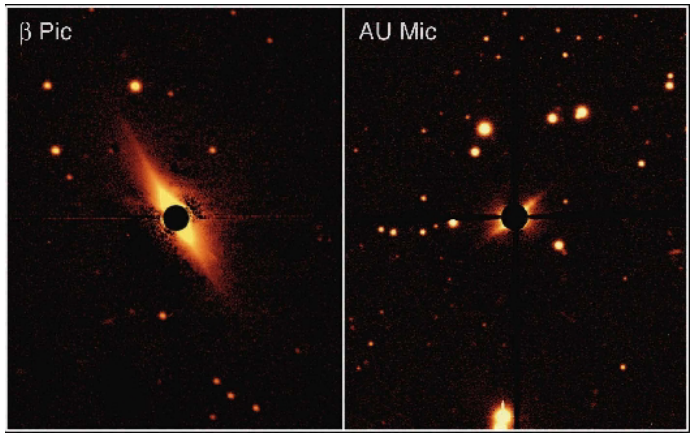
John Carpenter (Caltech)

- Motivation: long term goals
- Evolutionary timescales of dust and gas
- Evolution of spatial structure

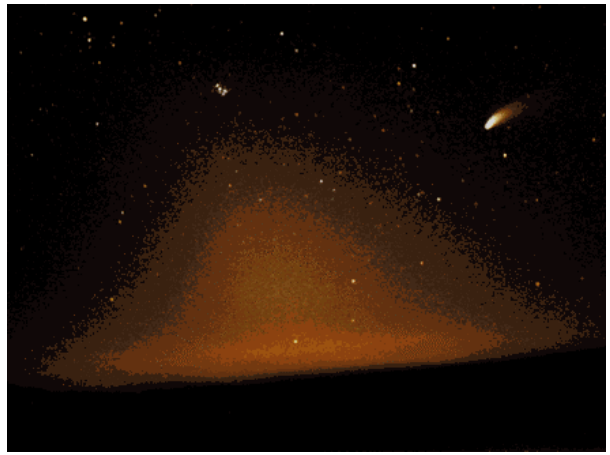
Evolutionary Stages of Disks



McCaughrean & O'Dell (1996)



Kalas et al. (2004)



Kalas

Accretion phase | **Post-accretion** | **Debris disks**

Gas giant planets - - - ?

Terrestrial planet formation - - - ?

Ice giant formation - - - ?

5 6 7 8 9 10

Log age (years)

Motivation

Long term goals

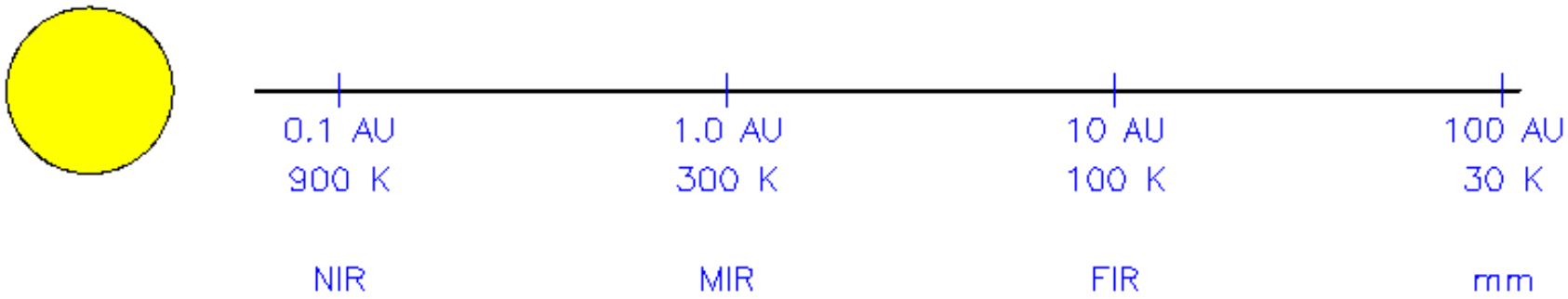
- When/where in disks do planets form?
- How common are planetary systems?
- What is the diversity of planetary systems?

Circumstellar Disks and Planet Formation

- What is the initial distribution of disk masses?
- How long do primordial disks survive?
- What is the spatial structure of disks?

Size Scales of Circumstellar Disks

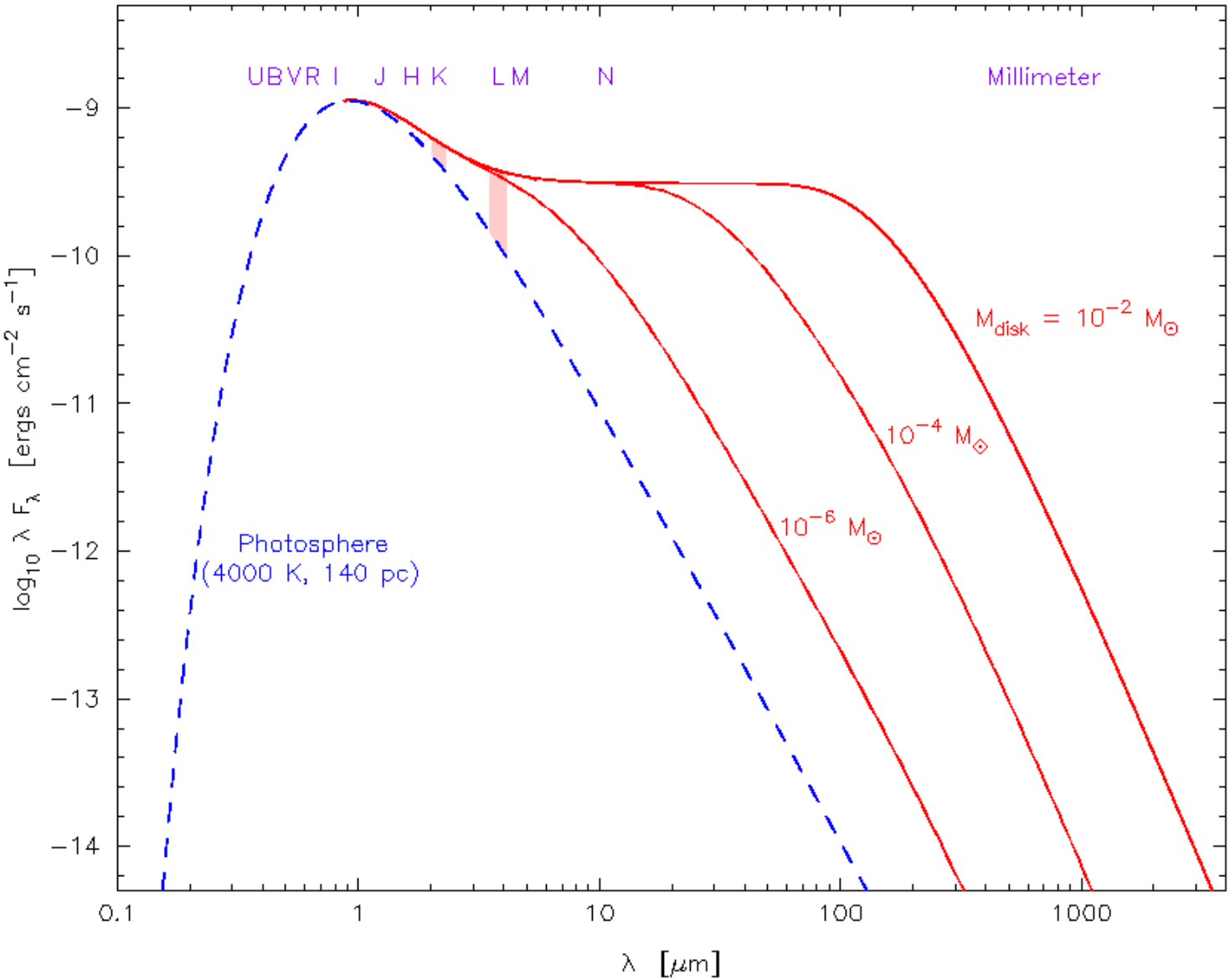
Circumstellar Disk



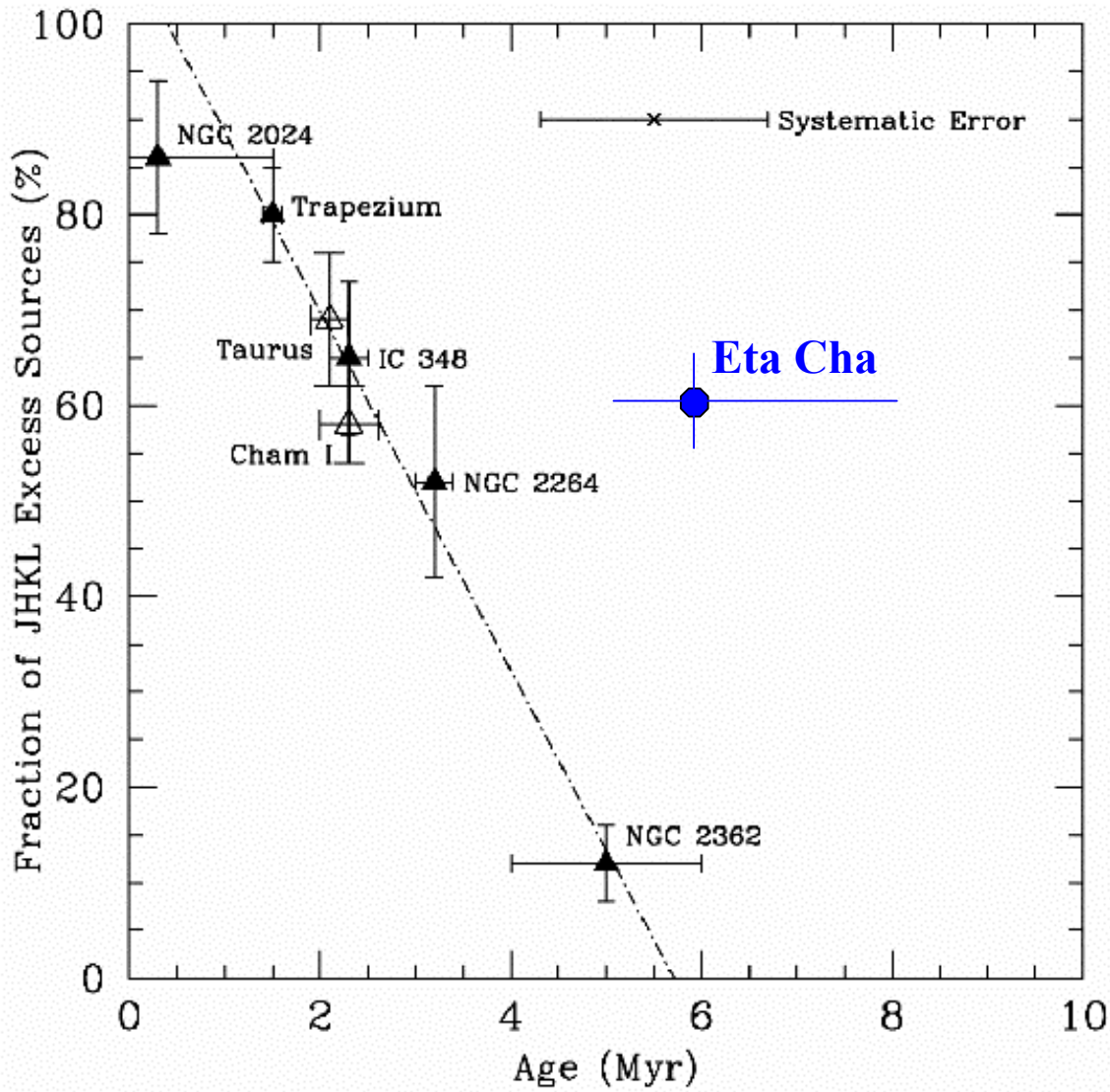
Solar System

Adapted from Najita & Strom

Near-Infrared Emission as Disk Diagnostics

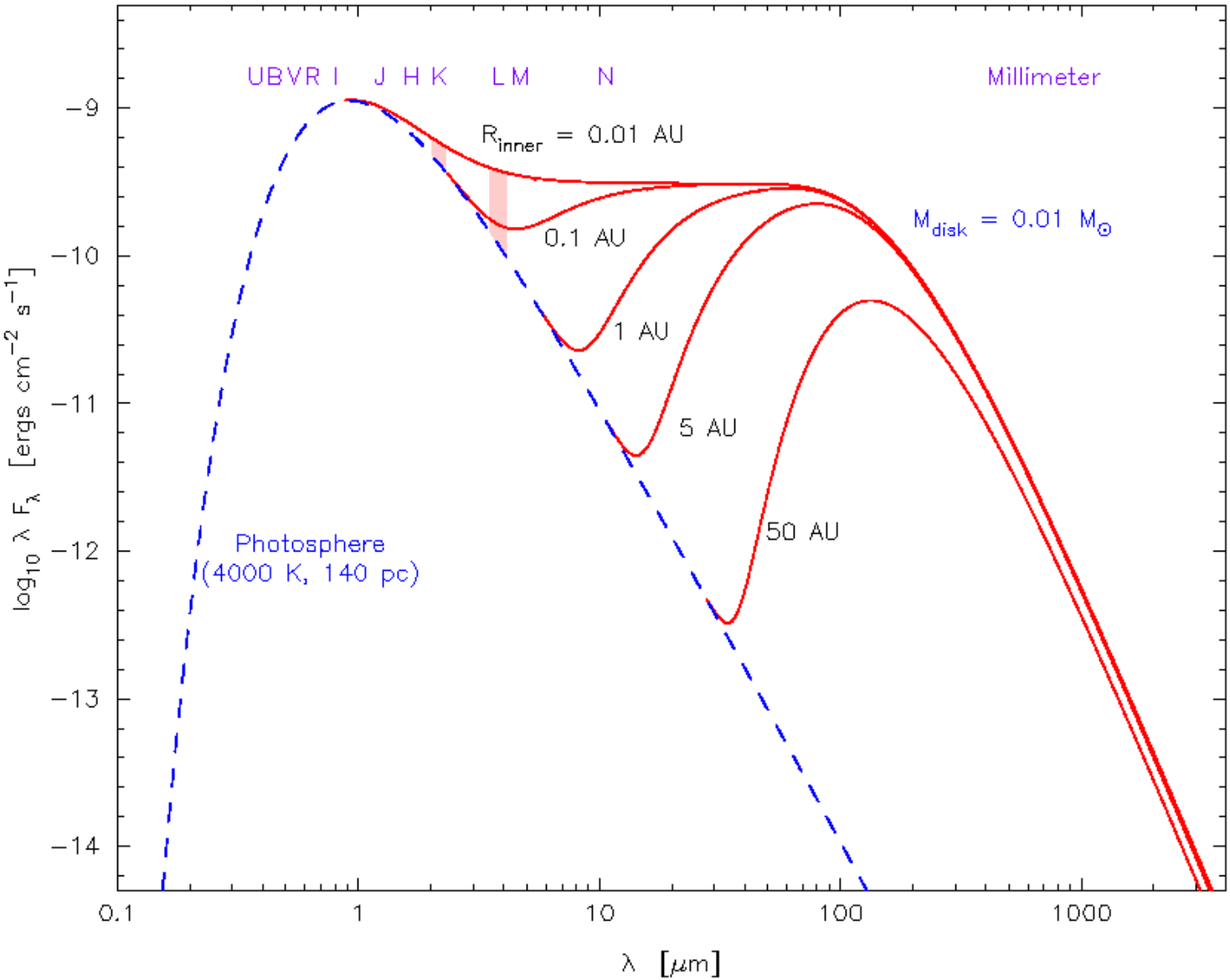


K-L excesses vs. cluster age

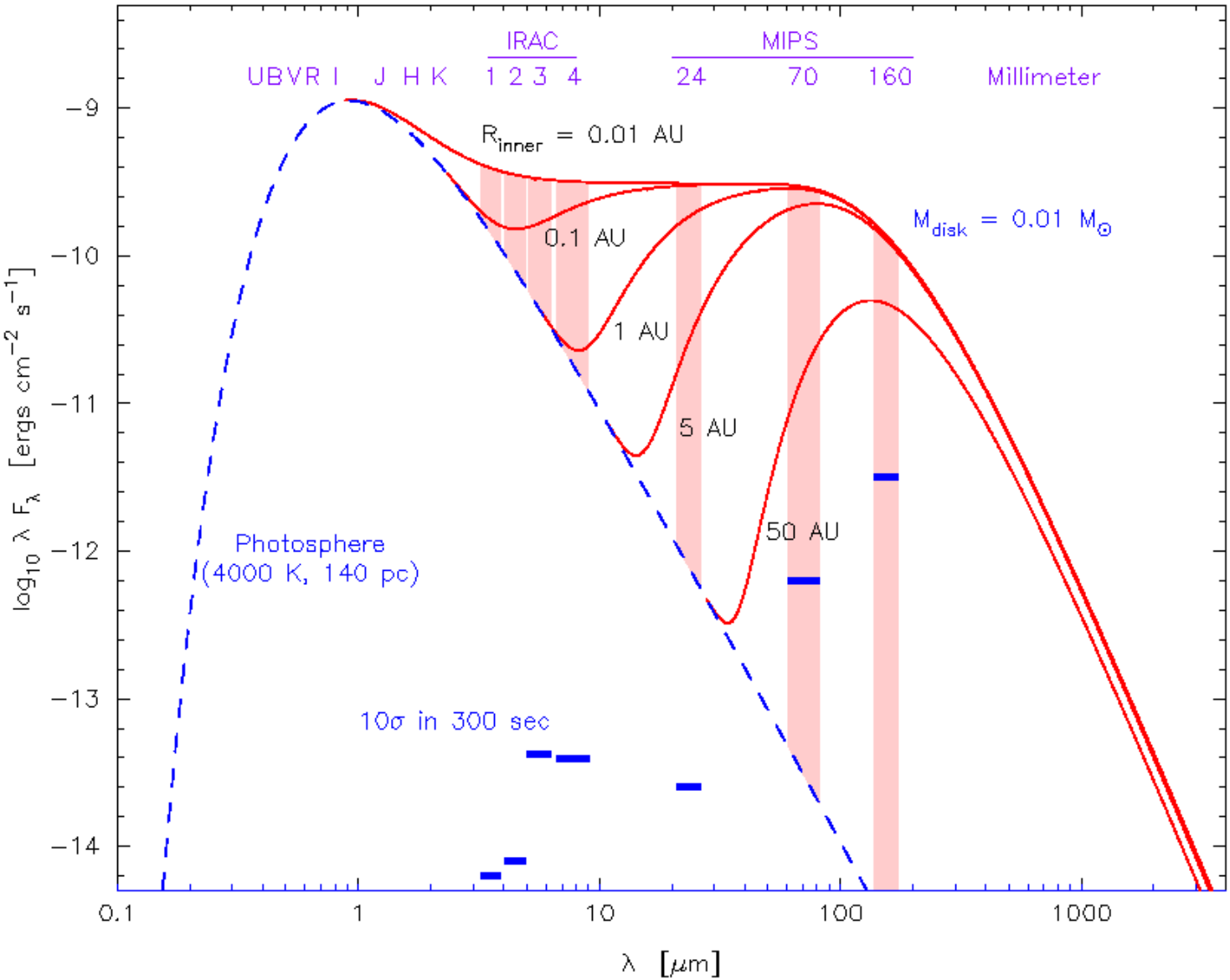


Haisch et al (2001, AJ, 121, 2065) Lyo et al. (2003, MNRAS, 338, 616)

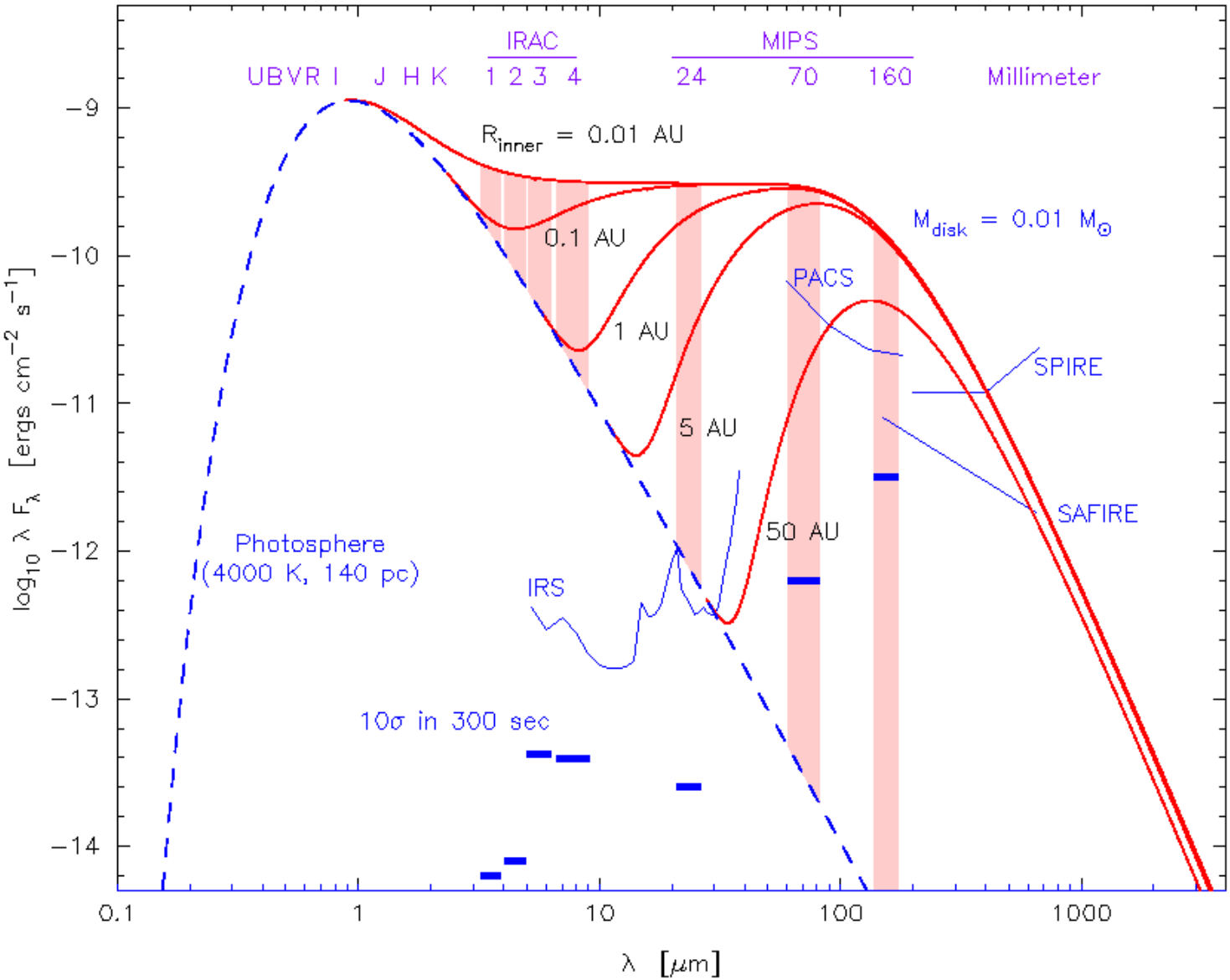
K-L Excesses and Inner Hole Size



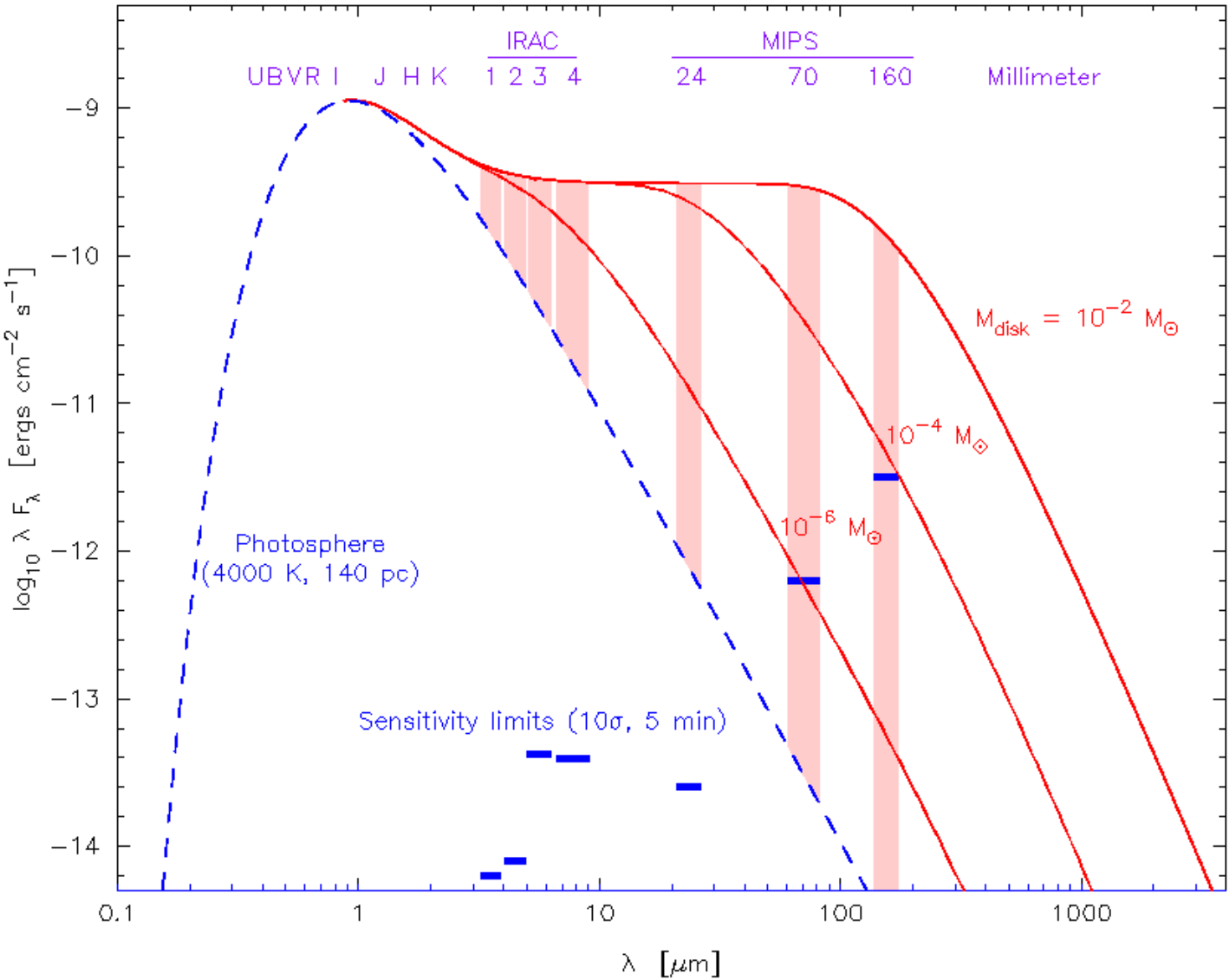
Spitzer Photometry



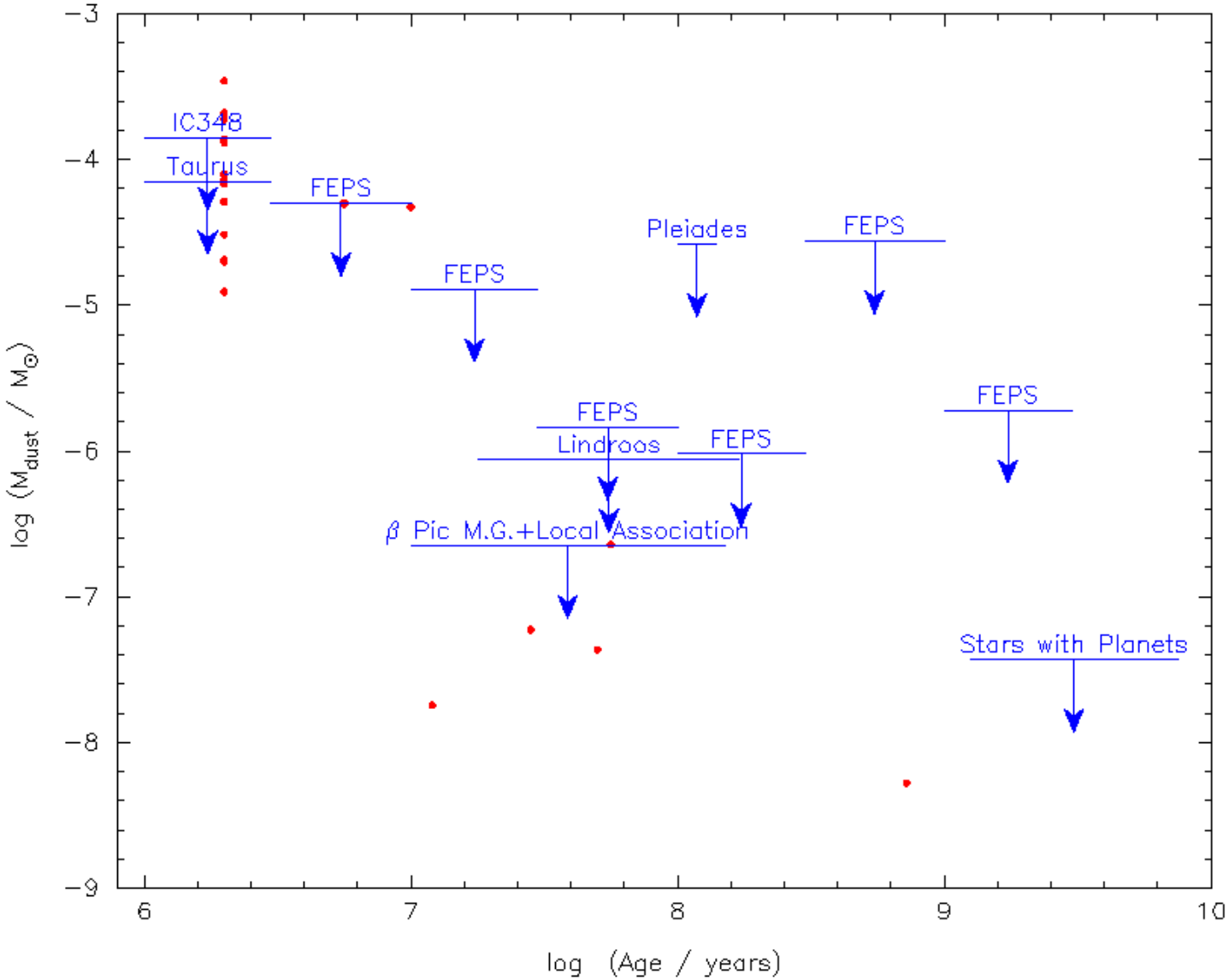
Spitzer/Herschel/SOFIA Spectrophotometry



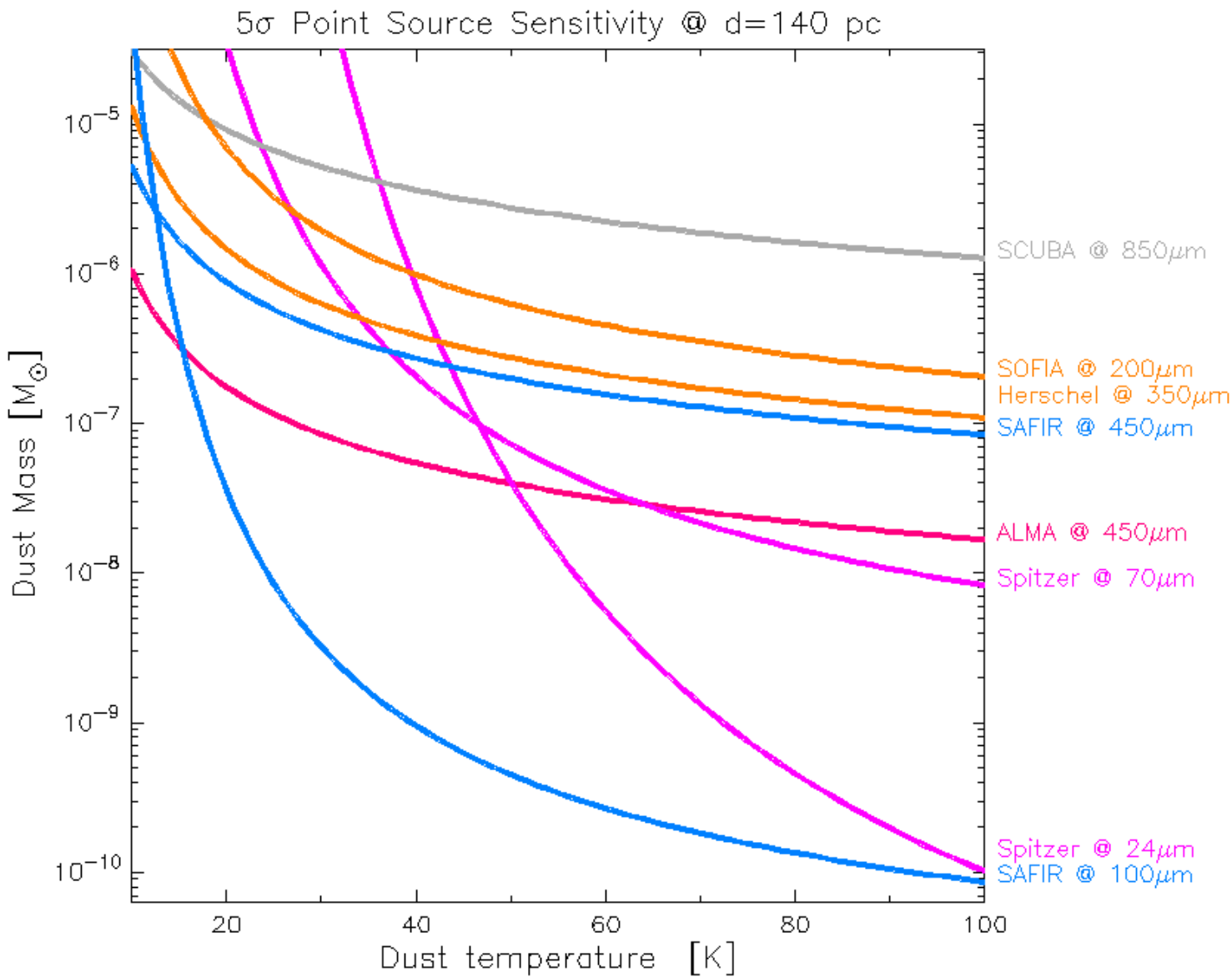
Sensitivity to Disk Mass



Dust Masses around 0.5-2 Mo Stars

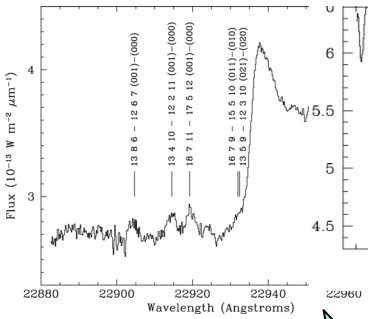


Sensitivity to Dust Mass

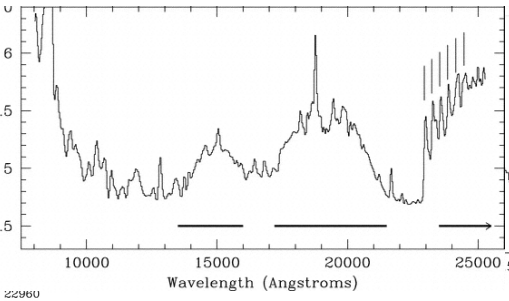


Molecular Gas in Disks

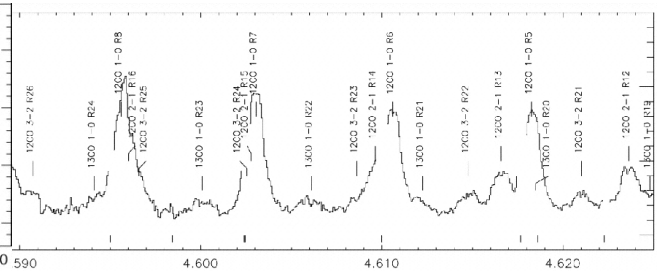
CO overtone



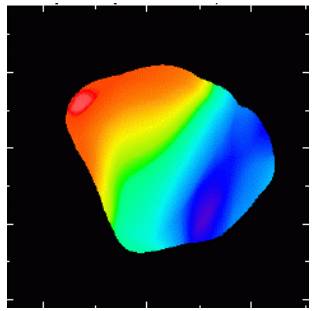
H_2O ro-vibrational

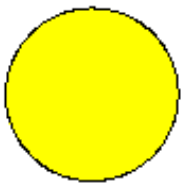


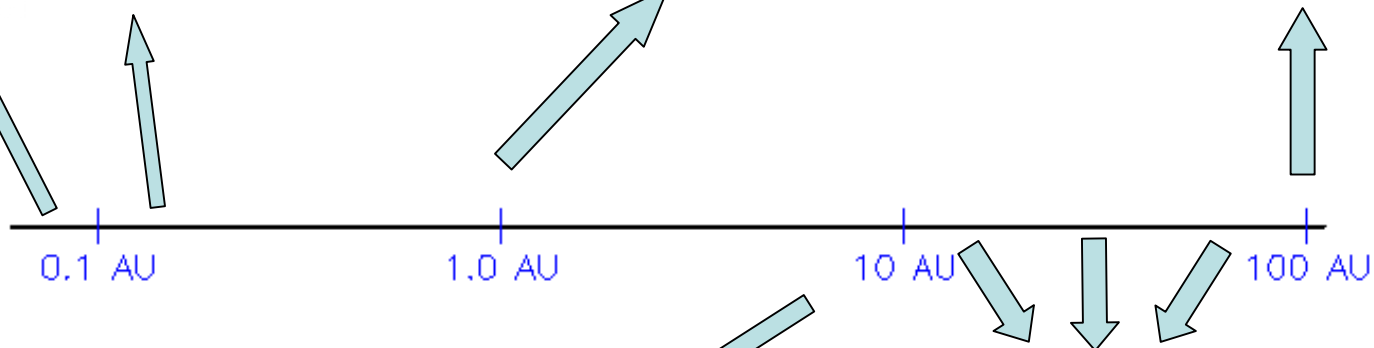
CO fundamental

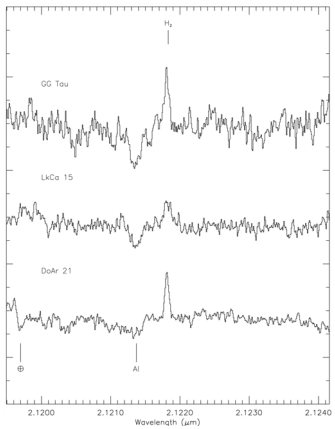


CO rotational





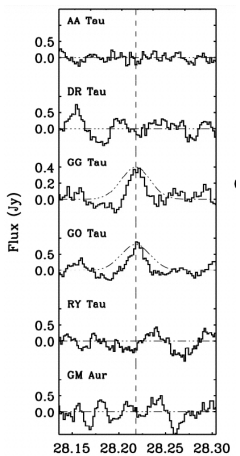




H_2 ro-vibrational

???

H_2 rotational



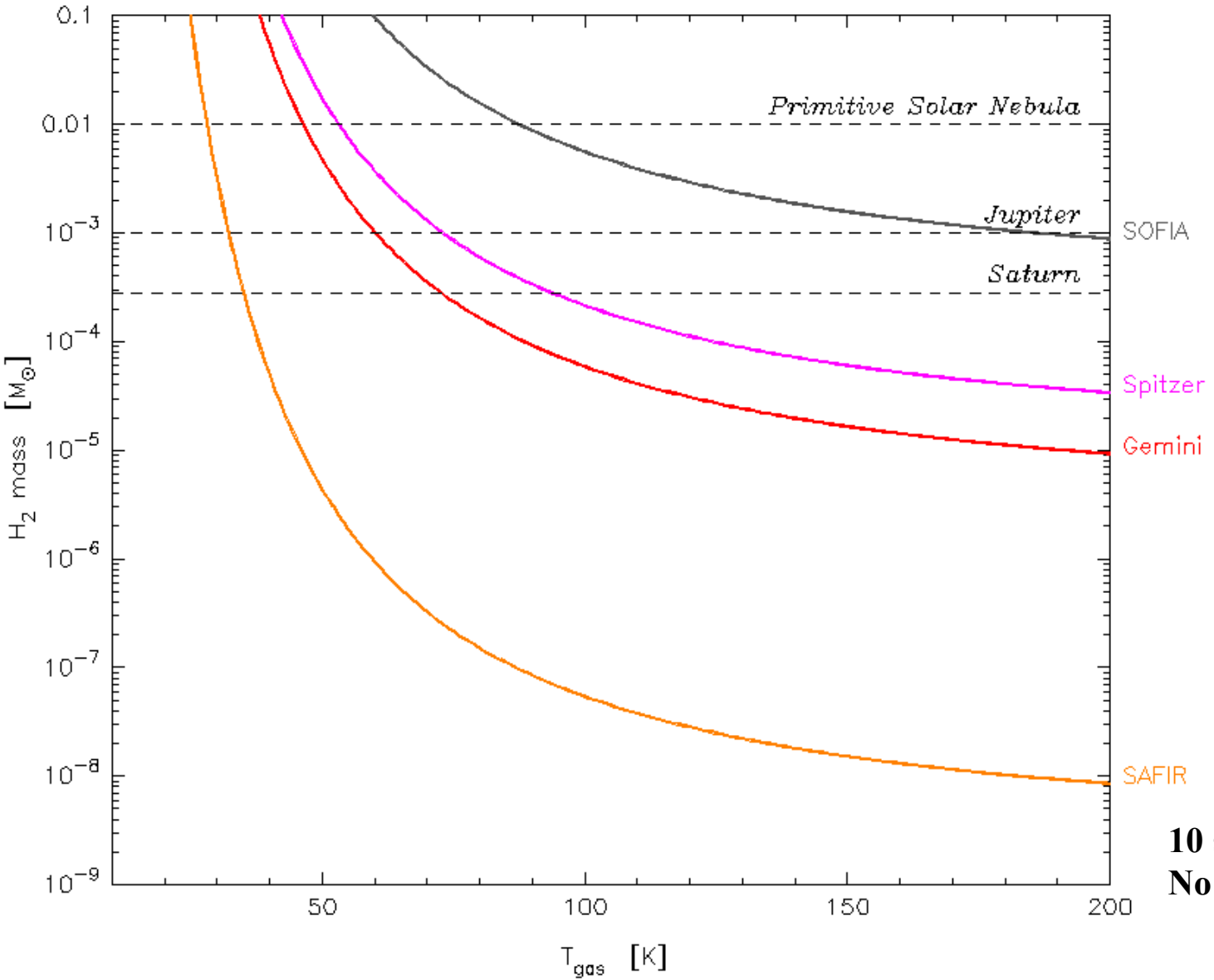
Diagnostics of Gaseous Disks

- Current Status
  - Young (~ 1 Myr) stars rich in molecular gas
  - H_2 results controversial (ISO vs. near-IR vs. UV)
  - Older stars typically lack CO (but see TW Hydra)
- Future Observations
  - H_2 (17 and 28 um)
    - Spitzer: R ~ 600
    - SOFIA, VLT, Gemini: R ~ 35,000
  - HD, H_2O, CO,…
- Ideally, want R ~ 10^5 - 10^6

  ⇒ Increased line to continuum ratio

  ⇒ Dynamical studies of the molecular gas

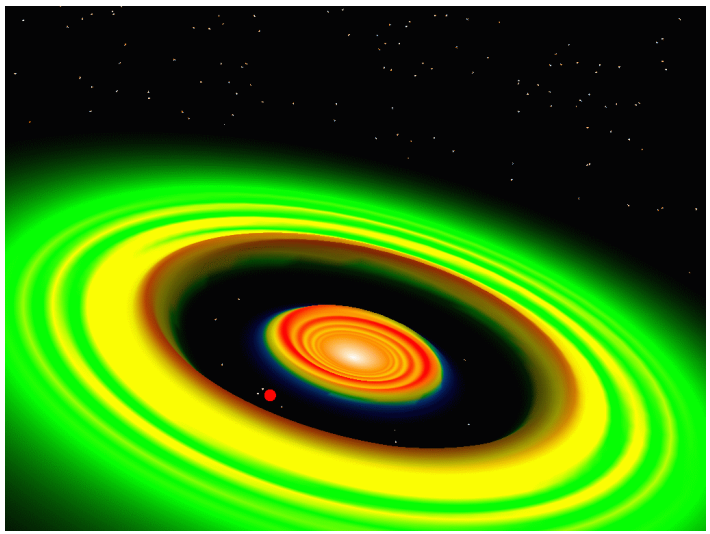
Sensitivity to Molecular Hydrogen (λ28 um)



10 sigma, 1 hour
No continuum

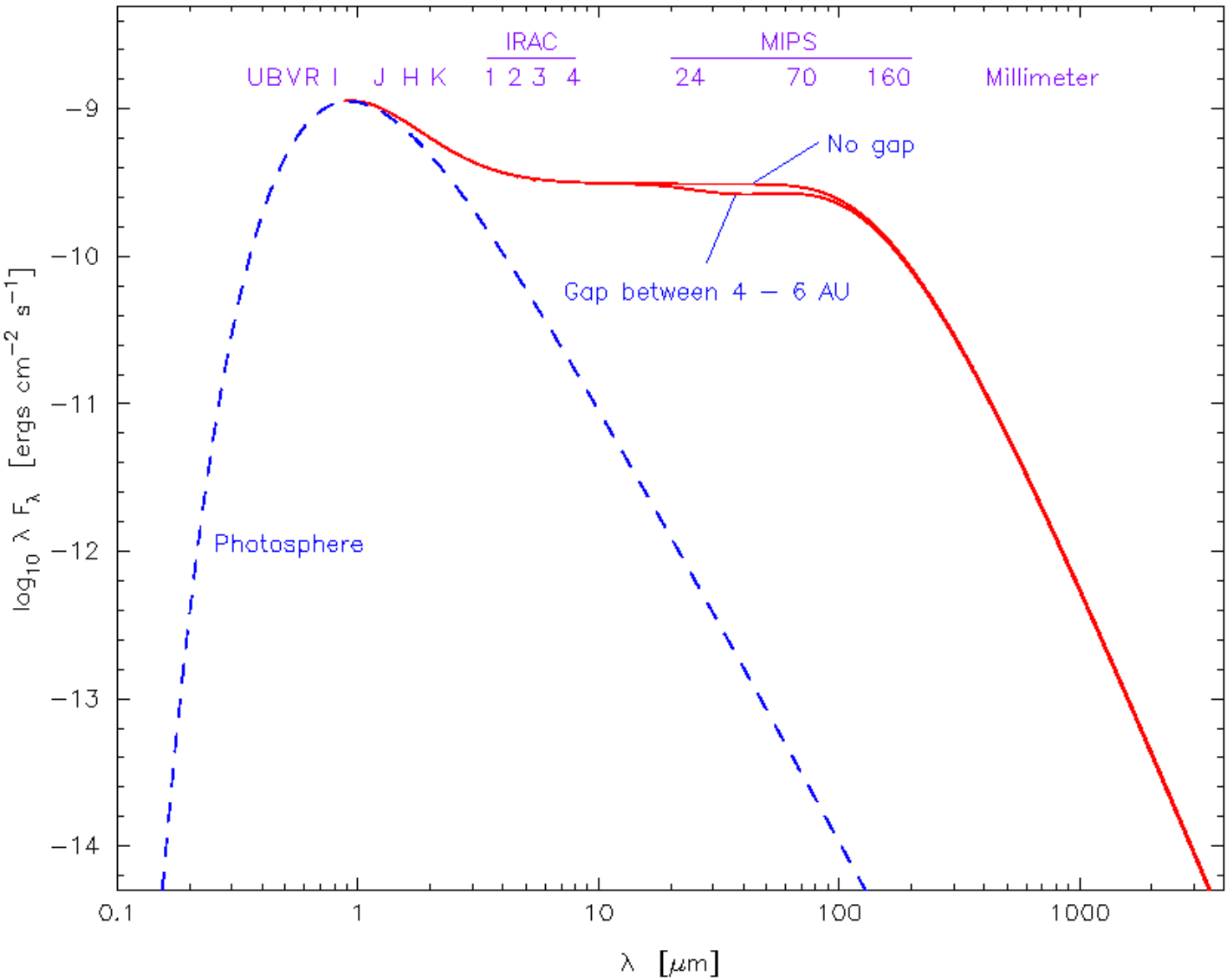
Spatially Resolved Observations of Disks

- *Critical* to remove degeneracies in SED models
  - M_{disk}, inclination, radius, flaring, composition, etc…
- Resolve gaps in disks
  - Potential signatures of orbiting planets

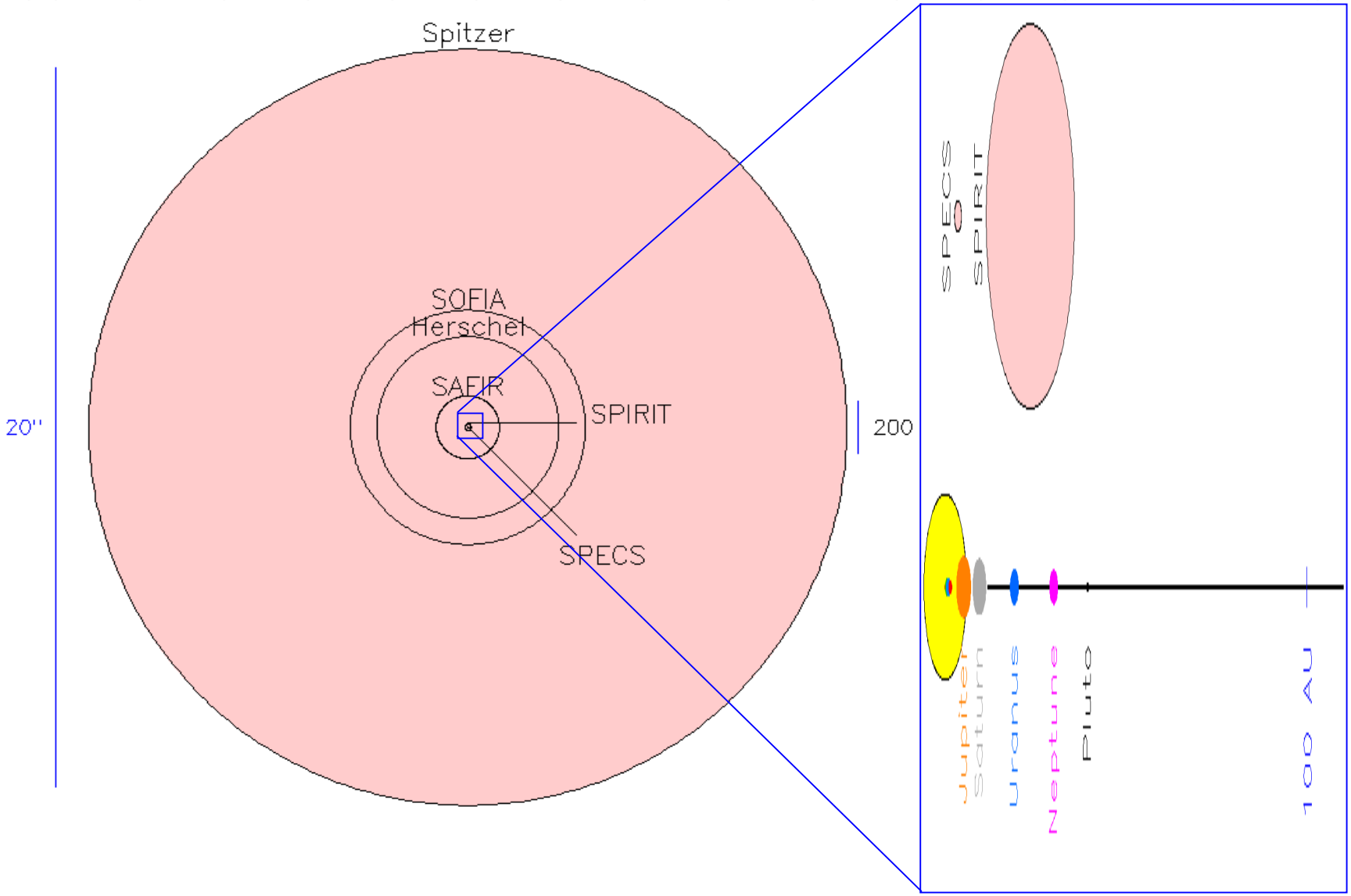


Geoff Bryden

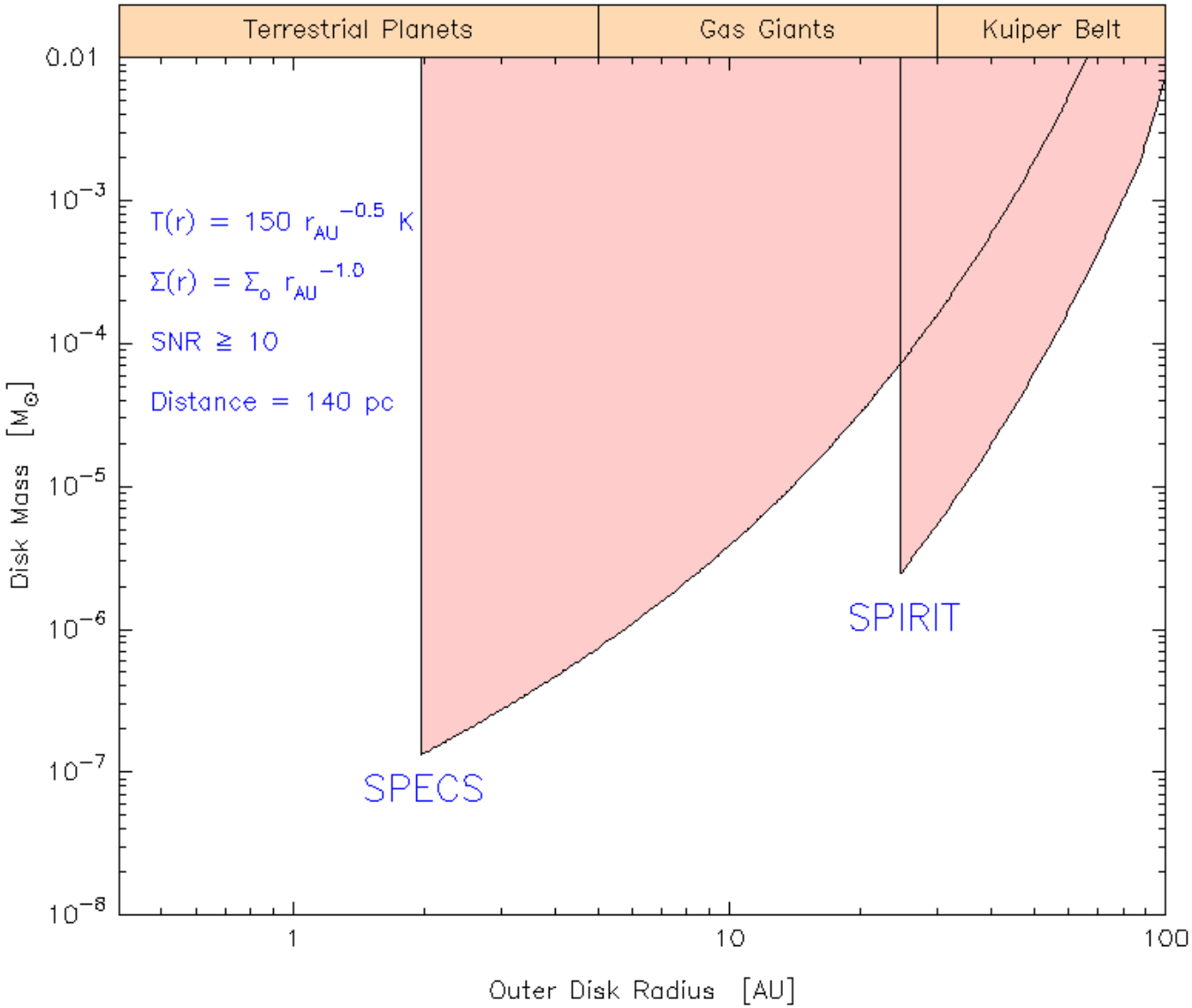
Inferring Gaps in Disks from SED's



Resolution at λ70 um, distance=140 pc



Imaging Disks with SPIRIT/SPECS @ 70um



Summary

- Dust evolution from SED's
  - Inner disk evolution will be well established (Spitzer)
  - Herschel/SOFIA to provide higher resolution for clusters and near continuous SED's from 5-500 um
- Gas evolution
  - Sensitive H_2 observations with Spitzer
  - High spectral observations required for sensitivity and kinematic analysis (SOFIA/JWST/SAFIR)
- Spatial resolved observations of gas and dust
  - Resolve disks on scale of primitive solar nebula (SPIRIT)
  - Resolve disks on gas-giant zones (SPECS)